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Helen Mitchard and Paul Taplin

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ABSTRACT

This report describes some of the functions that individuals within the Tactical Air Operations Centre (TAOC) may perform, and proposes software tools that may assist with battle management duties. In particular, we focus on the NORTHROC Operations Officer (NOPSO). We begin with a brief description of the TAOC environment and the duties of the NOPSO, followed by observations and interviews from Air Exercise Pitch Black 2000. The results of the analysis provide a basis for proposing various tools, which are described in terms of their function, advantages, disadvantages, feasibility and research interest. Finally, a particular set of tools is suggested for further development.

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Executive Summary

The design of software should support the tasks of the user. This report is the beginning of an effort to document the tasks of the NORTHROC Operations Officer (NOPSO), and identify those that can be assisted by software design.

The document is structured in the following manner. Firstly, there is a brief description of the NOPSO's environment in both an organisational and a physical sense. Subsequently, there is reference to domain familiarisation and two previous analyses, one using IDEF0 and the other using Cognitive Task Analysis (CTA). Existing software support is provided by the Phoenix Display System and occasional use of the Asset Visualisation Tool. Voice communication is also supported. Further analysis was based upon additional data sources such as interviews, exercise observations, and verbal protocols with subject matter experts.

From this work a number of possible software tools are suggested. The first four tools are aimed at assisting calculations over a very short timeframe, that is, the very tactical. These tools include an estimation of aircraft travel when lost from radar, an estimation of enemy fuel/remaining range, a time-to-target display, and an estimation of the latest possible scramble time for aircraft. The next three tools are to assist in assessing a possible threat, and they might be classed as external memory aids. They include a multi-attribute track history, alerts when aircraft deviate from expected behaviour and a searchable emitter library to help identify aircraft. The final tool suggested is a long-term asset schedular for radar and aircraft maintenance and relocation that would be of assistance to the Director of Operations and the NOPSO.

Each tool proposal is presented with a brief description of the problem and the aim of the tool to address it, the identified end-users of the tool, and a brief discussion of the benefits to the user. Some ideas for implementing the concept are given, together with the initial impressions of the data required for implementation. A discussion of the technical "do-ability" of implementing the proposed tool follows, listing the pros, cons, effort required, and opportunities to leverage off other work packages. Lastly, a discussion of the appropriateness of implementing a demonstrator of the proposed tool (based on the scientific contribution, task relevance and user benefits) is given.

The recommendations detailed are all achievable with current technology. A system, with a live feed, based on these recommendations could operate in a stand-alone mode, without having to be installed on existing hardware, and consequently, without impacting on current operations. Finally, we assign a priority to each concept, based on the identified need and the assessed feasibility of implementation. We intend to explore the concepts further in terms of requirements analysis, design, and implementation.

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Contents

1. Overview

This report describes a number of functions that individual air defenders within the Tactical Air Operations Centre (TAOC) perform, and proposes software tools that may assist with battle management duties, with particular focus on those of the Northern Regions Operations Centre Operations Officer (NOPSO). The report begins with a brief description of the Tactical Air Operations Centre environment and the duties of the NOPSO to orient the reader. Observations and interviews from Air Exercise Pitch Black 2000 are described, with the resulting analysis providing a basis for proposing various tools. The proposed software tools are described in terms of their function, advantages, disadvantages, feasibility, and research interest. Finally, as the first part of a more formal requirements analysis, a particular set of tools is suggested for further development.

2. The NOPSO's environment

The Joint Force Air Operations Centre (JFAOC) issues both positive and procedural directives to ensure airspace control. In addition, liaison, intelligence, operations and planning functions contribute towards the execution of air operations. A brief description follows.

Within the Royal Australian Air Force (RAAF), the Surveillance and Control Group (SCG) is one of the Force Element groups forming Air Command, the operational section of the RAAF. The SCG is responsible for developing a comprehensive air surveillance picture, particularly over our northern approaches, to enable effective Defensive Counter Air campaigns. SCG comprises a number of units within 41 Wing (41WG): the Surveillance and Control Training Unit (SACTU); No. 3 Control and Reporting Unit (3CRU) and No. 2 Control and Reporting Unit (2CRU); No. 114 Mobile Control and Reporting Unit (114 MCRU); No. 1 Radar Surveillance Unit (1RSU); and RAAF Air Traffic Control flights.

2CRU is located at Lee Point in Darwin and consists of the Northern Command Centre (NCC), the Regional Correlation Centre (RCC) and the TAOC, which together form the Northern Regions Command Centre.

The RCC provides the Wide Area Surveillance Picture (WASP). This centre provides an amalgam of short and long range radars, intelligence and civilian traffic information. The NCC provides the interface between the operational influence of the JFAOC and the TAOC. The TAOC provides the interface between the NCC and the ADF response elements.

The Director of NORTHROC Operations (DNO) resides in the NCC, which contains a number of sub-agencies that provide the DNO with advice. These agencies provide advice and guidance on intelligence, airspace coordination, law, logistics, communications, sensor, and systems issues.

The TAOC is headed by the NOPSO, who functions within the TAOC to provide airspace management, tactical direction, and fighter control support. Tools available to the NOPSO for battle management include:

- the Phoenix Display System (for radar and track information);
- TDRAP (for additional visualisation of the air picture);
- an Air Defence Operations Computer System (ADOCS) computer terminal;
- the Asset Visualisation Tool (AVT), which is built around a Gantt chart for visualising asset readiness and usage; and
- phone and radio lines.

The Air Defence Plan and Air Tasking Order, refinements of the directives from the JFAOC, provide the outlines and constraints for the TAOC's activities.

3. NOPSO Analysis

3.1 Previous work

The NOPSO performs a number of functions in the TAOC. Those functions pertain to both the complexities of leading a team and air defence. For simplicity we chose to focus on those activities that directly supported air defence.

In support of previous work to design a software tool to support the NOPSO, several studies were completed. Pitch Black 96 facilitated initial domain familiarisation for the report by McCloughry *et al.* (1997) which describes the layout of the NCC and the TAOC (then known respectively as the Sector Air Defence Operations Centre, or SADOC, and the Command & Control Centre, or CCC), and the staff roles and functions within the TAOC. In addition, IDEF0 modelling was carried out to provide analysis for the development of the AVT. This modelling had identified the main inputs, outputs, and activities of a NOPSO but mentioned some difficulty in sufficiently constraining the NOPSO's job to fit the IDEF0 framework (Taplin *et al.*, p.29).

The work described above provided data for domain familiarisation to inform the construction of a more detailed executable cognitive model of the NOPSO (Mitchard *et*

al., 2000). Further knowledge acquisition sessions provided opportunities to gather interview, observational, and verbal protocol data. Cognitive Task Analysis (CTA) techniques were applied to verbal protocols and interview data, enabling the identification of goal structures, and the procedural, perceptual, and declarative knowledge needed to perform the NOPSO's task.

As it was difficult to define the method of accomplishing the NOPSO's goal (namely, "to defend the airspace"), sub-goals were used to regulate task accomplishment (Hoc, 1988). That is, when the top-level goal cannot be defined precisely, the goal can be achieved through an ongoing process of satisfying sub-goals that are not necessarily in any predetermined order.

The NOPSO model constructed was based on the execution of four sub-goals that were identified:

1. The maintenance of situation awareness;
2. The prioritisation of threats;
3. The protection of all assets by the maintenance of the appropriate alert status; and
4. The management of fuel and weapons of friendly aircraft.

ADF documentation lists additional duties of the NOPSO as Advising the DNO of the current situation, and overseeing the TAOC operations and the functions performed by the Tactical Director (TACDIR), Air Controller (AIRCON) and Regional Surveillance Officer (RSO).

3.2 Existing tool support

The main geospatial display of the TAOC is provided by the Phoenix Display System (PDS, or generally, "Phoenix"). All personnel within the TAOC receive their own Phoenix picture on the screen of a personal computer running the Windows NT operating system. This picture is an amalgam of airborne tracks from various radar sources, augmented by the staff of the RCC with intelligence data that enables the resolution of inconsistencies. The map scale of each display can be adjusted by individual users to focus on particular geographic regions, and filters can be applied to display only track-types of interest. Other staff can add information about the fuel states and weapon loads of friendly aircraft in the air; however, in practice this function is not often used.

TDRAP is a DSTO-developed concept demonstrator that has been placed in the NCC to provide an additional geospatial view of the recognised air picture. A feed of TDRAP data can be made available to a terminal in the TAOC as required. It provides an alternative track fusion/resolution to that performed by the RCC, so that the user is able to consult this system if a track produced by the main tracking system (the

MV15000) disappears from their Phoenix display and they wish to maintain situation awareness.

The Air Defence Operations Computer System (ADOCS) receives a feed of data from the main tracking computer and is capable of producing an uncluttered recognised air picture to users with graphical workstations as well as providing tabular information to users with simple text terminals. The function of its geospatial display has been superseded by Phoenix, however, its simpler, tabular form provides additional information such as aircraft mission allocation, alert status, and requested and actual scramble times. This information can be updated at individual squadrons and viewed in the TAOC.

The AVT, as previously mentioned, is a DSTO-developed concept demonstrator that grew out of observations made at Pitch Black 96. The air defenders observed had a good appreciation of the geospatial information relating to their airborne assets, but had to resort to various external memory aids (ranging from shared magnetic whiteboards to personal notes) to better manage the current status of their ground-based and airborne assets. Some of this information was captured by ADOCS, however, users had to drill down through various levels of menus in order to find the data they required. Additional information, such as fuel and weapon states was not available, except to those who made requests via individual fighter controllers (FCs). The graphical Gantt chart visualisation of the AVT provided shared data and automated calculations to various users in the TAOC, better enabling them to conceptualise a large amount of temporal information at a glance.

Voice communications outside 2CRU are enabled via secure telephone and radio networks. Instructions and information from other NCC and TAOC staff are communicated via intercoms. The discussions are mainly liaison with other units such as the civilian air traffic control system, intelligence sources, Army and Navy units, and various support units. The NOPSO also communicates regularly with the DNO, who is in contact with Headquarters Air Command (HQAC), in order that information is relayed upwards to senior military decision makers, and to keep up to date with any variation of intent resulting from wider military or political considerations.

3.3 Further analysis of the NOPSO's task

3.3.1 Data collection

The additional data sources for this document were interviews, exercise observations, and verbal protocols with subject matter experts (SMEs).

3.3.1.1 Repertory grid interviews

In an effort to understand the physical characteristics of aircraft that contributed to threat assessment, repertory grids, a psychometric technique, were applied with RAAF personnel. Repertory Grid technique (Easterby-Smith, 1981) offers a means of eliciting some ordering of the attributes of members within a category. In this instance, the category was aircraft, and the technique was used to direct the interview to identify the relationship between threat level and physical attributes of the aircraft. The verbal protocols of the repertory grid process provided additional data.

3.3.1.2 Exercise observations and interviews

Pitch Black 2000 was a joint Air Defence exercise carried out in the Tindal/Darwin area of the Northern Territory during July 2000. Two wings were created for the exercise, 95WG, designated Offensive Counter Air (OCA), and 96WG, its counterpart, Defensive Counter Air (DCA). Aircrew and aircraft of a number of countries took part, and the resources of SCG were divided between the two wings named above. The TAOC, and consequently the NOPSO, were charged with defending the exercise airspace with the assets allocated to 96WG.

Voice recordings of the NOPSOs were made during exercise periods, together with a lesser number of physical observations. Verbal protocols were obtained from former NOPSOs during other exercise periods. These people were SMEs who had previously performed in this role and were able to observe, infer, and comment on the decisions of the current NOPSO, who would be unavailable for comment due to their high workload. As the exercise scenario did not vary greatly from window to window, the SMEs were familiar with the problem and able to provide data immediately.

3.3.2 Data analysis and results

The repertory grid interviews were transcribed. The repertory grids constructed, together with their transcriptions, provided cues and factors that were considered as part of the assessment of the threat level of a track. Interviews and observations from Pitch Black 2000 provided naturalistic data that has been analysed in a qualitative manner.

Cognitive task analysis of the threat assessment function performed by the NOPSO identified the following tasks and sub-tasks:

1. Maintain situation awareness:
    - Recognising new tracks;
    - Identifying tracks; and
    - Monitoring tracks.
2. Prioritisation of threats:
    - Assessing threat level of tracks.
3. Protect assets:
    - Devising the appropriate response to tracks.
4. Management of fuel and weapons of friendly aircraft:
    - Maintenance of the appropriate alert status.

The demands on the NOPSO for each of these tasks are briefly outlined below.

3.3.2.1 Maintain situation awareness

Both recognising new tracks and identifying tracks is primarily the job of the RCC. However the NOPSO revisits some tracks and consults with the RCC to check the consistency of the identification. Especially when some feature is contradictory to the assigned identification the NOPSO and the RCC may have frequent voice consultations to try to resolve the matter.

Of all the tasks, it could be argued that monitoring tracks is the most difficult of the various functions that the NOPSO carries out. The difficulty arises because of the many demands on the NOPSO's attention, the high load on memory, and the clutter of the geographical representation on the screen. However, it is a crucial task, as monitoring tracks enables the construction of a track history that assists in determining intent.

A functional level analysis of these sub-tasks led to the suggestion that tools of possible use would include a multi-dimensional track history and an estimation of aircraft travel when lost from radar.

3.3.2.2 Prioritisation of threats

The prioritisation of individual threats makes the task of situation assessment more tractable. The complex problem of assessing intent does not rely only on physical and temporal characteristics alone, as there is no clear demarcation between civil and other aircraft on radar revealed characteristics alone. Recognition of regular civil traffic removes a large number of aircraft from consideration; however, variance from normal flight times can make the task of correct identification more difficult. It is expected that information from The Australian Advanced Air Traffic System (TAAATS) may alleviate this concern.

More importantly the geospatial display is far from optimal in assisting the NOPSO to order the estimated arrival times of threats as the crucial information is not distance but time-to-target. As mentioned above, to augment the information on the geospatial display the NOPSO relies on information from the RCC. The importance of considering intelligence information when engaged in assessing the threat level posed by both individual and formatted aircraft cannot be overstated. Currently, the task of integrating intelligence information is purely cognitive, as there are difficulties in both transmitting and displaying this type of information.

For this sub-task, a functional level analysis indicated possible tools including a time-to-target display, alerts when aircraft deviate from expected behaviour, an estimation of enemy fuel/remaining range, and a searchable emitter library to help identify aircraft.

3.3.2.3 *Protect assets*

The first planning activity that the NOPSO engages in is the setting of a posture. In brief, a posture is an arrangement of ground and airborne radars and a number of aircraft at various states of readiness. This posture is based on the possibilities offered from the combination of intelligence on the enemy and Australian Defence Force (ADF) information.

Devising an appropriate response to threats is the second part of the planning that the NOPSO must engage in. The first part of the task is to determine whether a track should be engaged or not. If the assessment is that a track should be engaged then the NOPSO determines the appropriate time and location of the engagement. Once it is determined that the threat level of a track necessitates a response, Standard Operating Procedures (SOPs) and Rules Of Engagement (ROEs) constrain the actions that may be considered.

Testing of the NOPSO model indicated that when a threat is posed by fighter aircraft alone, that the presence of strike aircraft does not require higher alert states (Mitchard *et al.*, 2000). Similarly, observational data indicated that if the NOSPO had insufficient information about approaching tracks then they tended to assume the worst and prepare for self-defence.

A functional level analysis of this sub-task led to a suggested tool for estimating the latest possible scramble time for aircraft.

3.3.2.4 *Management of fuel and weapons of friendly aircraft*

In the process of maintaining appropriate alert status or mounting an effective defence, aircraft consume both weapons and fuel. Constraints such as fuel consumption and limited weapons affect the manner in which the NOPSO can change the air defence picture. Therefore, careful management of aircraft usage is essential.

An aircraft's fuel and weapons status determine the length of time it can remain airborne and whether the aircraft will be equipped to engage the opposition. An aircraft that has sufficient weapons, which doesn't require maintenance, and whose pilot is not fatigued, may be refuelled from an airborne tanker, otherwise it must return to an airfield and wait for an average forty minutes (up to an hour) to elapse before it can be ready to fly again. As the NOPSO's planning cycle includes not only the preparation and scramble times of aircraft, but the airborne, turnaround and release times as well, the planning cycle for this task is approximately 4 to 12 hours. Ideally, performance of this task will ensure the absolute optimisation of finite resources and prevent the NOPSO from creating a state where lack of maintenance fails to provide the necessary assets to deal with enemy aircraft. The Asset Visualisation Tool reduces the NOPSO's mental load assisting in the management of aircraft usage over the course of a day. However the AVT does not address other issues and consequently a functional analysis of this sub-task suggested a long-term asset schedular for radar and aircraft maintenance and relocation.

4. Possible Software Tools

4.1 Tool concepts

The purpose of this section is to present *functional* tool concepts and arguments that contribute towards an evaluation of each concept. We consider issues such as the resources necessary, feasibility of implementation and user benefits, and prioritise the tool concepts on these bases. Each tool concept is presented with the following fields:

Title	The tool's title.
Problem	A brief description of the problem and the aim of the tool to address it.
User(s)	The identified end-users of the tool.
Impact	A listing of the benefits to the user and possible measures of effectiveness.
Implementation	Some initial ideas for implementing the concept.
Information	A preliminary list of the data required for implementation.

Feasibility	A discussion of the technical "do-ability" of implementing the proposed tool, listing the pros, cons, effort required, and opportunities to leverage off other work packages.
Desirability	A discussion of the appropriateness of implementing a demonstrator of the proposed tool, based on the scientific contribution, task relevance, and user benefits.

Although elements of the graphical user interface or methods of interaction might be alluded to, it is the *functional* description that is of primary focus. Subsequent work will flesh out the "look and feel" of the tools nominated for implementation as part of thorough requirements determination and design phases.

4.1.1 An estimation of aircraft travel when lost from radar

Problem

When a track is lost from radar, either due to a system malfunction or because an aircraft has manoeuvred so as to be non-detectable, the track may cease to move or may disappear from radar screens. This results in a period of uncertainty and poor situation awareness. A tool is required which would display interim track positions until the normal condition is restored.

User(s)

- NOPSO, TACDIR, FC

Impact

A graphical representation of a track no longer updated by radar could enable the NOPSO to more fully maintain situation awareness by reducing the load on memory.

The representation of aircraft travel may be based on the last known heading and speed of a track, however this may have negative results if the NOPSO does not consider the implications of alternate directions of travel. To add an element of ambiguity, the aircraft's travel may be represented with an expanding "range ring", but this may supply no useful constraints—an expanding ring on its own might only provide vague or worthless information to the user—and merely clutter the display.

The heuristic might attempt to update the potential track position (with its element of uncertainty) until the link to the actual track is restored or an update on the current position is provided by communications with pilots. However, a constrained representation (using expanding wedges, for example) might instil a level of trust in information that might not be accurate.

This tool would provide a common picture for all users and greatly help in maintaining situation awareness, however, it might not see frequent use, as its benefit would only be evident during track loss or freeze.

Implementation
The use of "expanding rings" is an approach used in other systems, and described in the literature. The heuristics can range from the simple (where the ring is expanded at the same rate as the last known speed) to the very complex. An indication of the possible position of the aircraft might be shown by a shaded wedge within the range ring, based on information such as the last known heading and speed, and allowing for a certain amount of variation.

On tracks being "lost", a snapshot of the last known positions might be shown using specially marked track symbols. The user might choose to convert a small number of these symbols to expanding rings (as opposed to all of them instantly expanding) in an attempt to reduce clutter.

Information
The information required to implement this tool is available as Phoenix track updates, including last known position, heading, and speed. Logging of track updates would have to be performed to determine those tracks that are considered "lost" (that is, have not received an update for a given period of time or number of update cycles). Additional information may be required, as determined by the heuristics described in the literature.

Feasibility
- Medium:

Barring any great complexity suggested by the literature, the algorithm and visualisation for this tool seem achievable.

Desirability
- High:

The proposed tool fits well within the research aims of the task.

4.1.2 An estimation of enemy fuel/remaining range

Problem
An appreciation of the estimated remaining flying time for enemy aircraft is important for commanders to gauge the enemy's ability to sustain their effort, and to be able to discount tracks that pose a minimal threat because of the length of their outward journey. Well-trained commanders attempt to use "ball-park" figures for the remaining flying time of enemy aircraft by making "mental notes" of when they first appeared. This places an unnecessary workload on the commander. A tool is proposed which

attempts to more-accurately calculate remaining flying time and display the threat's remaining range.

User(s)

- NOPSO, TACDIR

Impact

The tool addresses a known task that the commander attempts to solve: to evaluate the threat posed by enemy aircraft and to adequately plan the defensive response. It is hypothesised that if the tool was used, a large reduction in mental workload could be shown. It should be noted that this tool is reliant on accurate intelligence information about the fuel tanks fitted to aircraft. This information can change on a daily basis. Information such as aircraft type and initial fuel load may not be available. Assumptions may need to be made to make this tool work, but this might result in inaccurate figures being presented. If this information is trusted, it may lead to critical errors.

The tool might also be useful for friendly aircraft, providing a more accurate approximation of remaining fuel for the AVT, for those times between updates provided by the pilots. A fuel model may be more accurate than a time-based one, but if displayed as pounds of fuel remaining this may cause too strong a focus on fine (and potentially incorrect) details. The result is probably best presented to the commander in broad terms of remaining flying time, for example, < 15 minutes, < 30 minutes, etc.

Implementation

The tool might simply record the time that the track was first detected, and assuming a certain type and fuel configuration, might indicate how long the aircraft has been airborne and how long it might reasonably remain so. (For example, a rule of thumb that is often used is that F/A-18 aircraft have a 90 minute flying time without being refuelled midair.) The results obtained by this method may be inaccurate if the tracks behave very differently from the model (for example, if one aircraft spends most of its time on CAP and another is flying at intercept speeds).

A preferable method would be to assume that an enemy aircraft is fully tanked when it is first detected, and then maintain a history of the aircraft's speed (and possibly altitude). These could be recorded into groupings that match the categories of a fuel consumption library. A calculated value for remaining fuel could be presented after every track update. A re-calculation using the grouped data could be performed when new intelligence comes to hand that changes the assumptions regarding aircraft type or initial fuel load.

Remaining fuel or flying time might be shown as a number somewhere on a display (such as with the track symbology), but essentially what the commander is trying to do is to determine the remaining range of an aircraft, and the threat that it poses. The use of a range ring around a track is a well-used technique that helps to show the possible

extent of an aircraft's travel, and would be updated if fuel usage was above or below the predicted expenditure.

Information
Information required for this tool include aircraft type and initial fuel loads (as assumptions set by the user), burn rates for specific aircraft at certain speeds and altitudes (loaded by the tool from a library of preset values), and track updates (including heading, height, speed, and position) from the Phoenix network.

Feasibility
- Medium:

A lot of assumptions need to be made regarding the track being studied, though barring any great complexity suggested by the literature, the algorithms and visualisation for this tool seem achievable. The validity of the tool could be tested against recorded Phoenix and AVT data for friendly aircraft. (The aircraft type and initial fuel load is known, and updates for the remaining fuel are logged.)

Desirability
- High:

The proposed tool fits well within the research aims of the task and seems like an interesting and worthwhile topic to research. The determination of an enemy track's remaining range forms the core of the larger problem of threat assessment and battle management.

4.1.3 A time-to-target display

Problem
Phoenix users have access to a feature that allows them to "rubber-band" a line between any two points in space and see the calculated distance and bearing displayed along its length. It is typically used by FCs to measure the distance between two tracks, so that pilots can be informed of their target's position if it is not visible to them (due to the aircraft radar's lesser range than that available to the TAOC). The NOPSO may use this tool to determine the distance of an enemy track to an ADIZ and then estimate a vague time it would take to get there. A new tool is proposed that would allow a permanent line to be drawn between a track and a fixed point, or between two tracks, with a calculated time-to-target value constantly updated alongside it.

User(s)
- NOPSO, TACDIR, FC

Impact
Offloading the calculation of time-to-target to the computer should result in a reduction in memory load on the user. The initial calculation will not only be more

accurate than the original estimate of the user, but will *remain* accurate with each new piece of track data that becomes available.

The tool's only limitation would come about because it relies on radar information: should an enemy aircraft avoid being detected, the tool would be of little assistance.

Implementation

Two modes of operation are envisaged: time to a stationary point, and time to a point of interception with another track. (The mode would be determined by the selection of either one or two tracks.) As just described, a permanent line would be drawn between the source and destination point/track, and the time-to-target values updated alongside it with each new track update that arrives for the tracks concerned. The values shown might include the time-to-target, distance, and bearing.

In the case of calculating time-to-intercept between two tracks, two lines would be drawn between the tracks to indicate the current bearing of one, with the calculated intercept vector of the other. As can be imagined, as the position, speed, and heading of the two tracks changes, the calculated intercept may move around significantly, or cease to be valid if no intercept is going to be possible. (How this latter case will be visualised will be left for later user-interface design. For example, should the intercept line not be drawn, or drawn short of the other track's bearing line?)

The inclusion of a "buffer zone" around a stationary point or intercept point would make an allowance for the proximity a track had to be to that point to make a kill with a weapon it could deploy. This would make most cases somewhat more realistic, as a track does not have to be coexistent in space with another before it can make an intercept. The additional information required (such as the weapon available and its characteristics) may make this extension to the tool a little too complex for implementation.

Further analysis will be required to determine whether the calculation for time-to-target should consider differences in altitude. It may matter little, because the speed provided by the track update (from a radar detection) is based solely on 2-dimensional latitude/longitude changes over time.

Information

The information required for this tool would be provided by track updates, including the latitude and longitude, speed, and heading, of either one or two tracks.

Feasibility

- High:

The only data required by this tool is available via track updates, and the calculations that need to be performed should be relatively simple. The larger effort will be that of providing a suitable, workable visualisation.

Desirability

- High:

This tool would have a number of immediate uses for various staff of the TAOC. It could be used to calculate times for intercepts between two aircraft, or the time for an enemy aircraft to reach a ground-based asset or a geospatial region (such as an ADIZ). Similarly it could be used for friendly assets to determine the time to reach a CAP, or the time for distant, friendly aircraft to merge in the air for the creation of a new flight.

These examples suggest that the ability to have multiple instances of this tool, on-screen at the same time, will be highly desirable.

Computationally, aspects of this tool would provide a core for Tool 4.1.4 ("Estimation of the latest possible scramble time for aircraft").

4.1.4 An estimation of the latest possible scramble time for aircraft

Problem

The management of the optimal defensive posture is crucial for successful defence. Although the principle of "meeting force with (equal or greater) force" will be the objective of the NOPSO, they will also be mindful of conserving the resources at hand and not committing forces unnecessarily or too early to a fight. Currently, NOPSOs estimate the latest possible scramble time for fighter aircraft using the distance-to-target of the approaching enemy and heuristics developed through experience. A tool that supports these mental calculations may enable more efficient use of assets.

User(s)

- NOPSO, TACDIR

Impact

This tool proposes a slight twist on the functionality provided by the Time-To-Target tool (4.1.3), in that, rather than calculating the location for an intercept given a *variable* speed, this tool would suggest the time it would take to get to a desired intercept location given a *specific* speed. The time difference between the time-to-target for the enemy aircraft and the intercepting aircraft affords a period of "slack time" when the aircraft, while on the ground, can be readied through a series of alert states and then scrambled at the optimal time. Together with a "position strength measure" calculated for each opposing side, and a heuristic (developed from a model of the NOPSO), a suggested alert state can be given for the readying and scrambling of a number of intercept aircraft from predefined locations.

The tool would not be prescriptive, but merely present suggestions on when aircraft could have their alert states changed. (By way of analogy, this could be much like the "hints" provided to the user by a computer in a chess game. A range of valid and

suggested moves are presented as options to the user, but ultimately it is up to the user to choose which, if any, of the moves they wish to take.) The tool might be used together with the Asset Visualisation Tool in proposing, managing, and executing posture plans, but whereas that tool relied solely on known information for friendly aircraft, this tool may be of little help in those situations where enemy aircraft avoid being detected by radar.

Implementation

There are four aspects of this tool that require design and implementation:

- A graphical user interface (GUI) that supports the definition of various, initial conditions;
- A suitable equation that defines an evaluation function for a position strength measure;
- Heuristics for suggested alert state changes; and
- An appropriate visualisation for the display of results.

Various initial conditions need to be specified, including the numbers and locations of available aircraft, their alert states, and a number of points in space that define a "trigger line", named as such because it triggers a response from the defenders. This line (which might define the same region as the ADIZ) would act as a reference for the calculation of an evaluation function that would provide a numeric "score" for the "strength" of the enemy, and for the defenders. The function could combine a number of variables into the score, but it might be that something as simple as the multiplication of the number of aircraft in the track by the closest distance to the trigger line could be summed together to yield a useful result. For the defenders to achieve an equal (or preferably, greater) score, they would have to increase the number of aircraft positioned close to the trigger line.

The application of various heuristics could suggest alternative alert states that would result in aircraft being scrambled at the appropriate time to yield a suitable position strength score. As previously mentioned, the alert state changes would be timed such that aircraft would be scrambled at the optimal time to meet the inbound enemy. The derivation of alternatives is far from a trivial activity, and it may be that it is something that only a human commander could ever hope to do well, but the "scoring" of a user's intended move with the evaluation function might enable them to explore different solutions and consider alternative courses of action (for example, moving ground-based aircraft to a higher alert versus moving airborne aircraft closer to the trigger line).

A visualisation of the results of this tool has not yet been envisaged. It may be that it uses a Gantt-chart-format like that of the AVT, or it may provide a written list of the top 10 options. At the very least, the "slack time" that a ground-based aircraft has before being scrambled could be shown, as could the calculated position strength score of the enemy and the defenders. These (and other) design issues will be left for further discussion with the intended users.

Information
Information potentially required to implement this tool includes the distance/speed of approaching enemy and defending aircraft (from Phoenix track updates), the location of the desired interception area (defined by user interaction with the GUI), and the number, location, and alert status of available fighter aircraft (maintained by the AVT and ADOCS). Various "fudge factors" may have to be considered to take account of the time taken to reach intercept speed from the initial order to scramble.

Feasibility
- Medium:

This tool relies on many types of information being available. If, for various reasons, the information is not available (or accurate) then the tool may prove to be of little use. Some doubt regarding the feasibility of this tool comes about because of the need to incorporate some potentially novel (and as yet, untested) algorithms and heuristics.

Desirability
- High:

This tool is the most complex of those outlined, and introduces elements of automation to the decision aids. Unless it incorporates well-tested and trusted heuristics used by NOPSOs, there exists a strong possibility that the posture changes suggested by this tool may be resisted by users. Further research will be necessary to determine an appropriate level of automation.

4.1.5 A multi-attribute track history

Problem
Phoenix users have a good appreciation of the geospatial information concerning the aircraft under their watch, but they have a problem with the visibility of other track data that changes "below the surface" of the interface, that is, not incorporated into and presented by the current visualisation. This information is not easily observable because any changes are gradual and subtle, or occur in time periods or physical locations that are not being watched. The current system can display this key information for the last update to the track, but to maintain an appreciation of the changes over time requires a massive load on the user's memory. A tool is proposed that logs the values of heading, height, and speed for a selected number of tracks over a period of time, and displays these in a way for the user to observe the track behaviour, thereby assisting in identification of aircraft type and possible intention. A software agent augmentation to this tool is presented as a separate tool in section 4.1.6.

User(s)
- NOPSO, TACDIR, and possibly staff of the RCC

Impact

By graphically presenting the track history over time, the user is more likely to detect behaviour that would otherwise be missed. The visualisation would build on the human ability to see complex patterns, enabling the NOPSO to perform threat assessment more accurately, with a lessened load on memory. A display of the raw, underlying track data would enable the user to choose appropriate conditions for the deviation alert tool (Section 4.1.6), and potentially identify why certain alerts failed to be raised (such as if the specified constraints were too narrow). Conversely, the visualisation may present too much clutter to the user, and act as a distraction, when all they really need is to be alerted to a particular change of interest. (Tool 4.1.6 addresses this issue.)

Implementation

The tool would display the change of value in an aircraft's heading, height, or speed as a stacked line chart, much like a stock market chart or computer system performance monitoring tool. The user would be able to set the maximum number of values to record in the history (for example, displaying the last 20 values only).

Information

The only information required to implement this tool is the Phoenix track data (such as track name, heading, height, speed, etc.)

Feasibility

- High:

The aim of the tool seems highly achievable, as the information required for it is automatically available via a feed of data being broadcast around the Phoenix network. The tool could be developed and tested with recorded Phoenix data.

Desirability

- High:

This tool aims at addressing a key difficulty faced by commanders in the TAOC, that of monitoring a situation over time and recording information changes that can be overlooked, due to geospatial visualisation deficiencies or operator inattention.

4.1.6 Alerts when aircraft deviate from expected behaviour

Problem

The visualisation provided by the multi-dimensional track history tool (Section 4.1.5) would help commanders identify track type and intent, but it still relies on the user having the correct track visualisation showing, noticing odd behaviour in the chart, and identifying important links between the data being watched. A tool is proposed that is like a software agent acting on the user's behalf, "watching" the raw data being visualised by the previous tool, and which alerts the user to a series of conditions being met (or constraints broken). Effectively, this would be like posing statements such as "I

think this is a civil track on route to X. Let me know if it does something it shouldn't be doing, such as going off-course more than 10 degrees", or "Let me know if a track suddenly descends, as though it is trying to fly below our radar".

User(s)
- NOPSO, TACDIR, and possibly staff in the RCC

Impact
Having a software agent observe the recorded data could reduce the workload of the user. However, trust is a major issue and this tool would require studies to identify the number of constraints that result in optimal use. The obvious issue is that the number of constraints chosen might result in too many (or too few) alerts, directly affecting the user's trust in the tool.

Implementation
Constraints could be entered for maximum, minimum, and difference values, such as maximum and minimum speed, change in speed, maximum and minimum height, change in height and change in heading. Complex constraints might be built using Boolean logic (eg. "Alert if height < 2000 and speed > 800"). A library of aircraft types might allow the user to easily load complex constraints based on known aircraft performance limitations.

Deviation in behaviour might be indicated via a track symbol being coloured differently and a small alert popping up next to it, or a small window might show a list of currently suspect tracks and the constraints they violated. This tool could be extended to watch other values such as latitude and longitude, or a range of points specifying a region that should not be left or entered.

Information
This tool would have no additional information requirements other than access to the data being logged by the multi-dimensional track history tool (such as heading, height, speed, latitude, and longitude). The suggested extension, a library of aircraft types, would require the once off entering of typical aircraft performance values.

Feasibility
- High:

Other than a period of fine-tuning some of the "watch values" (to minimise false alerts, or maximise desired alerts), this tool is algorithmically very simple in nature. The accuracy of alerts generated using this tool could be validated against known track types in the recorded Phoenix data.

Desirability
- High:

This tool successfully allocates a task to the computer to which it is perfectly suited: the rapid testing of a large number of (potentially) complex conditions. The human

commander is freed for complex decision-making, leaving the computer in charge as a "set of eyes" in a laborious task. And rather than implement a complex and potentially error-prone algorithm to identify what a track *is*, this tool offers to alert the user to a behaviour or situation for which *it is not*.

4.1.7 A searchable emitter library to help identify aircraft

Problem
A system that accepted ELINT data of aircraft radar signatures and IFF "squawks" could search a library of emitter data to produce a reduced set of possible matches to known aircraft types.

User(s)
- Primary users would be in the RCC (where the sensor data is available on the track when identification occurs).

Impact
The speed and accuracy of determining enemy aircraft type could be greatly improved.

Implementation
A well-designed graphical interface could access a complex database to allow searching on a number of variables.

Information
This tool could make use of data available to Phoenix (such as IFF modes), however it is more than likely that it would require access to the raw data that the MV15000 receives, prior to its fusion and dissemination to the Phoenix consoles. The software would also need to be built upon a database that is populated with a large dataset of typical radar signatures and IFF codes.

Feasibility
- Medium:

The ability to hook into an MV15000 data feed may prove problematic.

Desirability
- Low:

We expect that it may be more useful to look for unexpected aircraft behaviour (see 4.1.6) but the relative simplicity of this tool would allow a stronger focus on user-interface issues. The research appears to fall under the jurisdiction of DSTO's Electronic Warfare Division. In addition it falls outside of the scope of the task's TAOC-centred domain. Also it is not known whether a real need exists for a tool such as this, or indeed, whether a tool that performs this task is already in use by the RCC.

4.1.8 A long-term asset scheduler for radar and aircraft maintenance and relocation

Problem
Tools such as the AVT assist commanders in managing their aircraft over limited timeframes, typically in the order of hours. Longer-term campaigns require a management of other resources, such as the scheduling of OTHR radar coverage, movement of aircraft to the area of operations, and cycling of personnel to duty. An appreciation of asset availability and readiness over the course of days and weeks is essential for planning at the strategic and operational levels, but might also assist those at the tactical level in making more adequately-informed decisions.

User(s)
- DNO, NOPSO

Impact
A richer situation awareness could be achieved at the operational and strategic levels of command.

Implementation
A revisit to some of the aspects of the early AVT concept might prove fruitful. Initial intentions were to display assets other than aircraft on the time-based Gantt chart, such as the availability of OTHR radar feeds or other network issues. For example, commanders, on seeing that OTHR feeds would be lost for a period of time in the near future, might choose a more aggressive posture to compensate for the short time when they would be operating (relatively) "blind". Issues remain over whether such a tool would enable the user to compensate for a lack of information.

Information
Information required includes: radar status and scheduling; aircraft serviceability and availability (currently maintained on systems such as CAMM2); and various others, depending on the assets that would be modelled and visualised.

Feasibility
- Low:

Information regarding asset maintenance and availability would only be known at locations outside of the TAOC (namely, squadrons and radar surveillance units), suggesting that the system would need to extend far afield. A huge effort would be required to implement a tool such as this, even though it might only be an extension to an existing tool such as the AVT. It falls well outside of the bounds of an achievable concept demonstrator, given various personnel and time constraints, and the wider plans of this work to provide a *range* of decision aids.

Desirability
- Low:

This tool would be based on a known (and long existing) requirement, and would essentially be an extension to the current version of the Asset Visualisation Tool (as complex as that may be). The scope of such a system, from the NCC down to the squadron and radar surveillance unit levels, indicates a massive undertaking—much too complex for the purpose of a concept demonstrator. (This was the primary reason for the scaling back of the AVT's requirements.)

5. Conclusions

This analysis examined issues surrounding specification of new software tools for the NOPSO. Previous work carried out over the last few years, both descriptive and predictive, was revisited to provide background information on the NOPSO's tasks in the TAOC. Cognitive Task Analysis was performed to determine the information needs of the NOPSO that could be addressed by software design.

While contemplating the development of software tools the authors were mindful of the limitations of human working memory (Baddeley, 1986). Specifically, when working memory is overloaded, the obvious solution is to resort to memory aids, sometimes called external memory (Newell & Simon, 1972), however, such memory aids must themselves not add to the workload. Additionally, the appropriate allocation of tasks to the computer should allow the human user to focus less on computationally intensive, error-prone calculations, and more on complex decision-making issues.

In contrast to information overload, having *too little* information will result in a deficient level of situation awareness. The tools outlined here have illustrated the importance of improving the visibility of information that lies neglected or buried by the interface or inappropriate visualisation. A clear example is that of detecting a change in speed or altitude by a given track. The typical geospatial display focuses on latitude and longitude information, but fails to present information regarding speed or altitude in a meaningful way. This is a visualisation of information that a large number of people have access to, but that *no one can see*. There is little hope in detecting a momentary (though possibly, significant) event in a "cloud" of tracks.

The computer can support the user in a range of tedious monitoring and recording functions, such as notifying the user to conditions they should be mindful of, or updating time-based information with the passage of time. Compare this with the pursuit of "card counting" in a casino: though not necessarily a complex task in itself, it tends to be near-impossible for most people (without the aid of recording tools)—the player who has an ability to do this gains a definite edge. The analogy to be drawn is that the user does not necessarily require a fully automated tool, but could easily be assisted in areas in which they either struggle, or which consume too much time, taking their concentration from tasks that only they can perform.

The Battle Management tools outlined in this document aim to support the user in a range of cognitive areas, and are all achievable with current technology. They could form part of a more ambitious technological goal of an interactive, automated planner, but stand equally well on their own as simple, individual decision aids. It is envisaged that these tools would be operated in a stand-alone mode, receiving live Phoenix track data from a network, without having to be installed on existing hardware, and consequently, not impacting on current operations.

In this final section we have tabulated the author-assigned priority of each tool concept, based on the identified need and the assessed feasibility of development. Based on this, OPSOs from various countries will give their opinions on interface designs for the first six tools. For the development and evaluation of software prototypes the RAAF, in particular the SCG, must delegate resources.

Table 1: Summary of feasibility/desirability assessments to determine tools worth pursuing.

Tool	Feasibility	Desirability	Investigate
A time-to-target display	High	High	✓
A multi-dimensional track history	High	High	✓
Alerts when aircraft deviate from expected behaviour	High	High	✓
An estimation of aircraft travel when lost from radar	Medium	High	✓
An estimation of enemy fuel/remaining range	Medium	High	✓
An estimation of the latest possible scramble time for aircraft	Medium	High	✓
A searchable emitter library to help identify aircraft	Medium	Low	✗
A long-term asset schedular for radar and aircraft maintenance and relocation	Low	Low	✗

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Appendix A: Abbreviations

114MCRU	No 114 Mobile Control and Reporting Unit
1RSU	No 1 Radar Surveillance Unit
2CRU	No 2 Control and Reporting Unit
3CRU	No 3 Control and Reporting Unit
41WG	41 Wing
ADIZ	Air Defence Identification Zone
ADOCS	Air Defence Operations Computer System
AIRCON	Air Controller
AVT	Asset Visualisation Tool
CAP	Combat Air Patrol
CCC	Command & Control Centre
CTA	Cognitive Task Analysis
DCA	Defensive Counter Air
DNO	Director of NORTHROC Operations
FC	Fighter Controller
GUI	Graphical User Interface
HQAC	Headquarters Air Command
JFAOC	Joint Force Air Operations Centre
MV15000	(Computer system underlying Phoenix displays)
NCC	Northern Command Centre
NOPSO	NORTHROC Operations Officer
NORTHROC	NORTHern Region Operations Centre
OCA	Offensive Counter Air
PDS	Phoenix Display System
RAAF	Royal Australian Air Force
RCC	Regional Correlation Centre
ROE	Rules Of Engagement
RSO	Regional Surveillance Officer
SACTU	Surveillance And Control Training Unit
SADOC	Sector Air Defence Operations Centre
SCG	Surveillance and Control Group
SME	Subject Matter Expert
SOP	Standard Operating Procedures
TAAATS	The Australian Advanced Air Traffic System
TACDIR	Tactical Director
TAOC	Tactical Air Operations Centre
TDRAP	Technology Demonstrator Recognised Air Picture
WASP	Wide Area Surveillance Picture

Appendix B: List of interviewees

Name	Cat	Organisation
SQNLDR Steve Borbiro	AIRDEF	DSCA
SQNLDR Peter Cooper	AIRDEF	114MCRU
SQNLDR Tracey Friend	AIRDEF	2CRU
SQNLDR Richard Pizzuto	AIRDEF	41WG
SQNLDR Krista Thompson	AIRDEF	SACTU
WGCDR Daryl Eggins	AIRDEF	41WG
WGCDR Daryl Hunter	AIRDEF	1RSU
WGCDR Graham King	AIRDEF	2CRU
WGCDR Ken Watson	AIRDEF	3CRU

Table 2: List of Interviewees

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19. ABSTRACT

This report describes some of the functions that individuals within the Tactical Air Operations Centre (TAOC) may perform, and proposes software tools that may assist with battle management duties. In particular, we focus on the NORTHROC Operations Officer (NOPSO). We begin with a brief description of the TAOC environment and the duties of the NOPSO, followed by observations and interviews from Air Exercise Pitch Black 2000. The results of the analysis provide a basis for proposing various tools, which are described in terms of their function, advantages, disadvantages, feasibility and research interest. Finally, a particular set of tools is suggested for further development.

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